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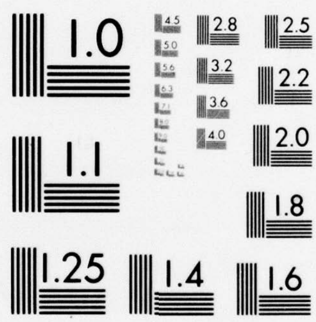

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Study of Symbology for Automated Graphic Displays

by

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An extensive literature survey indicated a great variety of available alternative symbology formats. Before a specific format is selected, the necessary information requirements for a particular position must be determined. For Army tactical displays, this information should be gathered in experiments using realistic battle scenarios. As a related effort, alternative symbol formats were evaluated by civilians. Naive subjects generally preferred a pictorial symbol over traditional military alternatives. The report is written for a military audience.

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STUDY OF SYMBOLOGY FOR AUTOMATED GRAPHIC DISPLAYS

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FOREWORD

The Fort Hood Field Unit of the Army Research Institute for the Behavioral and Social Sciences (ARI) provides support to Headquarters, TCATA (TRADOC Combined Arms Test Activity). This support is provided by assessing human performance aspects in field evaluations of man/weapons systems.

A war using modern weapons systems is likely to be both intense and short. US man/weapons systems must be effective enough, immediately, to offset greater number of enemy weapons systems. Cost-effective procurement of improved or new combat systems requires testing that includes evaluation of the systems in operational settings similar to those in which the systems are intended to be used, with troops representative of those who would be using the systems in combat. The doctrine, tactics, and training packages associated with the systems being evaluated must themselves also be tested and refined as necessary.

This report presents the results of a literature review, and an investigation of sets of alternative symbol rankings for relatively naive subjects. The study and literature review specifically addressed the problems in the development of more effective symbologies and the information requirements for automated graphic displays used in tactical operations systems.

ARI research in this area is conducted as an in-house effort, and as joint efforts with organizations possessing unique capabilities for human factors research. The research described in this report was done by personnel of the Human Resources Research Organization (HumRRO), under contract DAHC19-75-C-0025, monitored by personnel from the ARI Fort Hood Field Unit. This research is responsive to the special requirements of TCATA and the objectives of RDTE Project 2Q763743A775, "Human Performance in Field Assessment," FY 1978 Work Program.

JOSEPH ZEIDNER
Technical Director

STUDY OF SYMBOLOGY FOR AUTOMATED TACTICAL GRAPHIC DISPLAYS

BRIEF

Requirement:

The work carried out in this study is that referred to in paragraph 2.2.11 of the Statement of Work (revised) dated 16 May 1977 under the title "Symbology for Automated Graphic Displays." The following objectives guided the course of the study:

- To review the present requirements the Army perceives as essential and/or desirable types of information to provide on a real-time basis to commanders during combat.
- To review the literature for relevant studies pertaining to automated graphic display symbology and human perceptual and information processing capabilities and limitations.
- To investigate the perceptual meaning perceived in several alternative types of symbols, particularly by relatively untrained observers.
- To produce a statement to assist developers of symbologies in optimizing information processing by users of tactical automated graphic display systems.

Procedure:

Literature and reports were obtained from the Defense Documentation Center (DDC) and University of Texas libraries (Austin) which appeared to be relevant to the areas of symbology and graphic display. In addition, locally available reports in these areas were obtained from TCATA. The obtained material was reviewed and abstracted for:

- Data and findings pertaining to the activities and information requirements of tactical commanders.
- Research findings related to user capabilities and limitations in handling computer-displayed symbologies.

Secondly, an investigation was designed and conducted to evaluate the preferences of naive subjects for various types or styles of symbology. Subjects were 25 civilian employees from West Fort Hood, Texas.

Principal Findings:

- Current automated graphic display equipment and technology such as the CCIDES facility at TCATA appears to be capable of handling the display requirements for investigating many alterative and/or supplemental symbologies.
- Alternative symbology forms appear to appeal to naive subjects as a function of their graphic pictorial similarity to the concept symbolized.

Utilization of Findings:

The primary product of this research review and investigation is confirmation of the need for more complete task analyses of the functions and outcomes expected from the duties performed by those personnel working with tactical operations systems. Concurrent development of alternative graphic symbology format(s) to facilitate performance of such duties should be undertaken where necessary.

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Chapter 1

BACKGROUND

The primary purpose of this report is to describe the current status of symbology development for use in interactive graphic display systems such as the Command and Control Interactive Display Experimentation System (CCIDES). A secondary purpose is to examine user requirements for such systems when employed as a part of a Tactical Operations System (TOS). [cont'd on 1473]

A hundred years ago, fighting units consisted of foot soldiers, horse cavalry, and horse-drawn artillery. Battlefields were often of a size that permitted a commander to view the entire battle area from a hilltop vantage point. Under these conditions the table-top situation display was quite adequate. The geographical area portrayed was quite small, and the number of different symbols required was minimal. Rapid movement of units was a rare event, so frequent updating of the display was not a requirement. Now, with mechanized infantry, armor, missile and rocket installation, supersonic aircraft, and airmobile units, the variety of symbols required has greatly proliferated. The battlefield may well encompass hundreds of square miles, and rapid mobility makes frequent updating a necessity. The interest in a new symbology stems largely from the vast increase in the number of different types of units or functions that must be represented, and the display congestion resulting from use of current symbologies.

The origin of the CCIDES system is described by Aldrich, et al.[1] These workers examined three candidate systems with differing automated display technologies: (1) the Scribe system developed by the Northrup Corporation, (2) the Cathode Ray Tube (CRT) system developed by the General Dynamics Corporation, and (3) the Photochromic system developed by the Singer Librascope Corporation. These systems differ primarily in the technology used to develop imagery for rear projection of dynamic symbology. The work was conducted at Headquarters, Modern Army Selected Systems, Test, Evaluation, and Review (MASSTER). The overall purpose of the effort can be translated into three objectives: (1) the determination of how such displays can best support tactical operations; (2) the evaluation of proposed requirements under operational conditions; and (3) the suitability of the three candidates in meeting the proposed requirements critieria. At the conclusion of the study, the General Dynamics system was procured for further study and was designated CCIDES.

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[1] H. B. Aldrich, et al. *IBCS: Automated Displays*, MASSTER Test Report FM 116, Headquarters, Modern Army Selected Systems, Test, Evaluation and Review (MASSTER), Fort Hood, Texas, July 1974.

Aldrich, et al., in their discussion, cite the following from Parslow, Prowse, and Green:[2]

> Graphic data processing provides a common language of graphics and alphanumerics between the man and the computer. A man normally thinks in terms of sketches, drawings, graphs, letters, characters, and numbers. A computer operates in terms of bits, bytes and registers.... With the advent of graphic data processing, the man can continue work in the medium he understands best;..., with the graphic display console acting as an interpreter between the two. This new dimension in man-machine communication has proved to be of value in applications where: Graphic representation is of assistance in the performance of the application or Rapid turn-around time is required, or Human imagination, judgement [sic], or experience is required in the solution of the problem.

As the authors further emphasize, the key to user acceptance is proper definition of user requirements and the ease with which the user can interact with the system.

The present report focuses on those factors which affect not only user requirements, but also user performance. It is of little value to have the technological capability of satisfying the requirements of a particular user if factors which affect user performance are not considered in developing the system output. Meister and Sullivan[3] list 12 system output factors which affect the performance of users of interactive graphic display devices. These display parameters are:

1. Display size
2. Character size
3. Type of display (e.g., CRT, large screen, readout)
4. Brightness/contrast
5. Resolution
6. Viewing distance
7. Viewing angle
8. Type of character (e.g., alphanumeric, symbol)
9. Color and other forms of coding

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[2] R. D. Parslow, R. W. Prowse, and R. E. Green. *Computer Graphics*, New York: Plenum Press, 1969.

[3] D. Meister and D. J. Sullivan. *Guide to Human Engineering Design for Visual Displays*, Defense Systems Division, Bunker-Ramo Corporation, Canoga Park, California, August 1969.

10. Character/background relationship (light letters on dark background, dark on light)
11. Number of characters presented on the display
12. Frame (change) rate.

These 12 factors may influence individual symbol legibility; however, the human operator acts upon his interpretation of the entire display. He must not only be able to accurately and rapidly perceive individual symbols, he must also make decisions and take actions on the basis of the total information presented. Therefore, consideration must be given to the development of presentation techniques suitable to the requirements of the different users of the display. Table 1-1 lists some of the potential users of information displays at division level and below. Currently, expanding the use of computer-generated graphics

Table 1-1. Activities That Use Information Displays*

Division	Brigade	Battalion
G2 (Operations-Plans)	S2	S2
G2 Air	S2 Intelligence Team (BICC)	S2 Intelligence Team (BICC)
G2 Intelligence Team (BICC)	S3	S3
G3 (Operations-Plans)	S3 Air	S3 Air
G3 Air	Fire Support Coordination Center (FSCC)	FSCC
Fire Support Element (FSE)	TACP	TACP
Airspace Control Element (ACE)		
Signal Intelligence Support Element/ Electronic Warfare Element (SSE/EWE)		
Tactical Air Control Party (TACP)		

*Reproduced from H. B. Aldrich, et al. *IBCS: Automated Displays*, MASSTER Test Report FM 116, Headquarters, Modern Army Selected Systems, Test, Evaluation and Review (MASSTER), Fort Hood, Texas, July 1974, p 41.

to corps level is being actively considered. Increasing the number of users will undoubtedly widen the variety of information that must be conveyed by computer-graphic displays. Earl[4] reviewed four reports concerned with defining essential elements of information for G2 operations at division level, and listed those elements included in one or more of the presentations. Over 100 different information categories and subcategories were considered essential for G2 operations. There will undoubtedly be some overlap between G2 information requirements and those of other activities. However, additional information peculiar to the other activities is also likely to be needed. As a result, information from a wide variety of both personnel and electronic sources will have to be integrated and made available for presentation. Considering the potential magnitude of these requirements, it is easy to understand why Army authorities feel that the day of using only the manually constructed situation display is over. In addition, the map background upon which this information is or can be displayed itself increases display requirements and creates scaling problems. As Trelinskie[5] states:

> Boundary areas for a hypothetical corps-level combat zone can normally be fitted to three 1:250,000 scale topographic map sheets. The same coverage area using 1:50,000 scale maps requires the use of 75 map sheets.... In conducting the process of terrain analysis, this figure of 75 map sheets is compounded. For most terrain analyses, anywhere from 11 to 20 terrain factor overlays are generated for each 1:50,000 topographic map sheet used in the study area.... In terms of terrain graphic volume, a corps-level area terrain analysis requires the generation and control of at least 75 topographic map sheets at the 1:50,000 scale along with 814 terrain factor overlays.

When graphically displayed information is overlaid onto a terrain display, the resulting mass of information may become so congested that it cannot be easily interpreted. The Army has been and is continuing to consider alternative solutions to this problem of displaying increasing

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[4] W. K. Earl. "Research Plan to Develop Military Symbology for Tactical Automated Graphic Displays," US Army Research Institute for the Behavioral and Social Sciences (ARI), Fort Hood, Texas, 1978.

[5] E. Trelinskie. "Management of Terrain Information," paper presented at *Symposium on Computer Graphics in Support of Tactical Command and Control*, Headquarters, TRADOC Combined Arms Test Activity (TCATA), Fort Hood, Texas, August 1977.

amounts of information. Methods amenable to computer transmission and display of maps and other hard copy have been developed by the US Army Engineering Topographical Laboratories. The CCIDES facility already has the capability to digitize standard or special maps for complete or selective projection on the display, or can, alternatively, project a map directly on either the CRT display or the rear projection screen. Examples of other approaches under investigation may be found in studies of analog processing by Murphy and Trelinskie,[6] and computer simulation by Brooks, et al.[7] Bramley[8] presents an up-to-date assessment and forecast for those interested in further details within this area.

The Project Manager of the Army Tactical Data Systems (PMARTADS) is responsible for the design, development and integration of the hardware aspect of computer driven and other tactical display systems. The present report examines user requirements which, along with concept of operations and training needs, are established by the Training and Doctrine Command (TRADOC), particularly through elements of the Combined Arms Combat Developments Activity (CACDA). HQ, MASSTER, which was under TRADOC, was designated TRADOC Combined Arms Test Activity (TCATA) in 1976, and is currently conducting research to identify automated techniques, procedures and applications to improve support of tactical military command and control activities. Research consists primarily of discrete subtests (called workshops) conducted on CCIDES. Figure 1-1 illustrates the CCIDES configuration used in one workshop. Further details of the hardware configuration are available in a report by Gaustad, et al.[9] along with the results of the Intelligence Analysis Application. Additional studies utilizing the CCIDES capability include

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[6] L. P. Murphy and E. G. Trelinskie, Jr. *Analog Graphic Processing for 3-D Terrain Displays, Profiles, and Elevation Layer Tints*, US Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, October 1975.

[7] J. Brooks, L. Lichtenstein, and H. Steinberg. *Computer Simulation of Terrestrial Scenes*, US Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, July 1975.

[8] J. Bramley. *Display Technologies for Topographic Applications. Assessment of State-of-the-Art and Forecast*, US Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, June 1975.

[9] P. J. Gaustad, H. R. Van Gorden, M. H. Kroger, E. N. Sowell, and I. W. Larson. *Tactical Operations Systems Applications and Software Experimentation - Intelligence Analysis Application*, MASSTER Test Report FM 271-1, Headquarters, Modern Army Selected Systems, Test, Evaluation and Review (MASSTER), Fort Hood, Texas, May 1975.

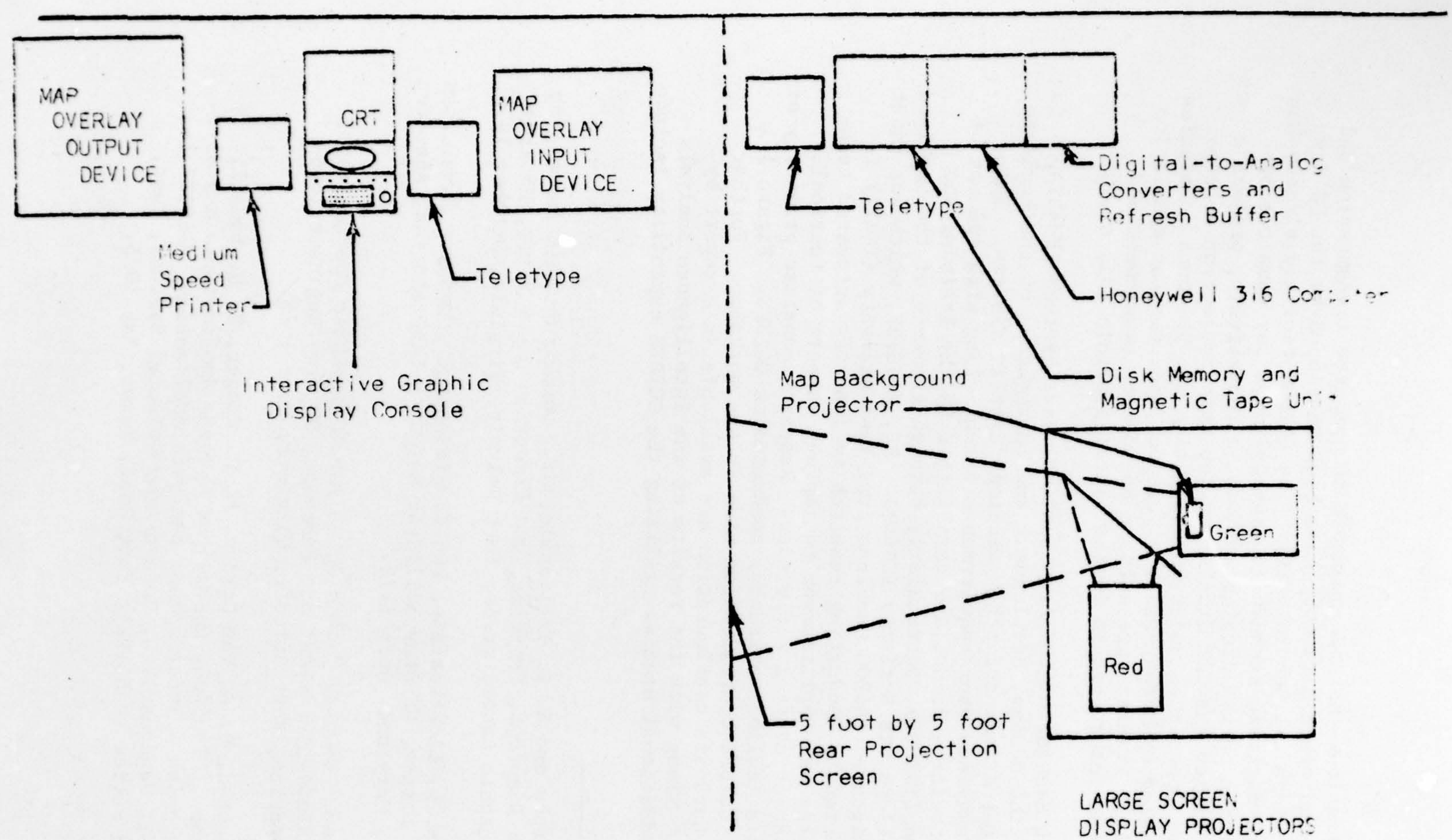

Figure 1-1. CCIDES configuration for intelligence analysis workshop.*

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*Reproduced from P. J. Gaustad, M. H. Kroger, I. W. Larson, H. R. Van Corden, and E. N. Sowell. Tactical Operations System Applications and Software Experimentation - Intelligence Analysis Application, MASSTER Test Report No. FM 271-1, HQ MASSTER, Fort Hood, Texas, May 1975, p 10.

Tactical Road Movement Application,[10] Trend Analysis Application,[11] Tactical Templating,[12] and User Perception of Graphic Display Requirements.[13] These studies are concerned primarily with the CCIDES capability to perform certain specific functions, and in most instances, it performs them satisfactorily. Several of the conclusions and recommendations contained in the final report[14] on these CCIDES studies are directly relevant to the thrust of the present report. One of the conclusions is that present symbology is effective, but users vaguely sense that it could be improved. Another is that the minimum essential symbology has not been determined. The final report recommends further investigation of the optimum symbology for computer-generated tactical displays.

The current symbol format used in the CCIDES displays is much more compact than prose, but it lacks information that might be of considerable importance to a decision-maker. Indicators of unit capability such as effective strength, fire power, morale level, and supply level would be desirable. Also, the symbols representing as many as 80 or 90 units assembled in a small area of the battlefield become extremely cluttered on a small CRT display. Symbols tend to overlap and mask others, or they must be so reduced in size that they become illegible. The current symbology has also been criticized on other grounds. Frequent criticisms are that the details are difficult to learn and remember, and that extraction of meaningful information is difficult. Also,

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[10] P. J. Gaustad, H. R. Van Gorden, M. H. Kroger, E. N. Sowell, and I. W. Larson. *Tactical Operations System Application and Software Experimentation - Tactical Road Movement Planning Application*, MASSTER Test Report No. FM 271-2, Headquarters, Modern Army Selected Systems, Test, Evaluation, and Review (MASSTER), Fort Hood, Texas, March 1975.

[11] J. A. Cooper, et al. *Tactical Operations System Application and Software Experimentation - Trend Analysis Application*, MASSTER Test Report No. FM 271-3, Headquarters, Modern Army Selected Systems, Test, Evaluation, and Review (MASSTER), Fort Hood, Texas, December 1975.

[12] J. D. Reed, et al. *Tactical Operations System Application and Software Experimentation - Tactical Templating*, TCATA Test Report No. FM 271-4, Headquarters, TRADOC Combined Arms Test Activity (TCATA), Fort Hood, Texas, July 1976.

[13] N. M. Hayden and A. J. Swartz. *Tactical Operations System Application and Software Experimentation - User Perceptions of Graphic Display Requirements*, TCATA Test Report No. FM 271-5, Headquarters, TRADOC Combined Arms Test Activity (TCATA), Fort Hood, Texas, September 1977.

[14] *Ibid.*

while many of the symbols do appear to be iconic representations of unit function, such as an airplane propeller for aviation, some seem to have lost their association value. The bandoleer for cavalry and the crossed rifles for infantry are examples. Even some of the newer symbols appear to have little compelling association value, such as the radar dome for air defense ⌒ and the V or Y for airmobile units. Thus, there are strong arguments for the development of new symbologies which can convey desired information clearly and quickly and are simple enough to be generated by computer with minimal clutter and confusion. Ringel, et al.,[15] in their discussion of the critical functions or operations involved in utilizing automated tactical operations systems, list five critical functions of information processing: (1) screening of incoming data, (2) transforming raw data for input into storage, (3) input for compilation and display, (4) assimilation of displayed data, and (5) deciding on a course of action. It is at Step 4 that symbology becomes a critical factor in command and control. Parsons and Perry[16] have a similar perception of command and control and provide a lengthy but excellent discussion of what they term the "military process." Their analysis of command and control functions use the terms *Sense* (incoming communications), *Analyze, Decide,* and *Act*, and they point out the problems which can arise at the interfaces of each of these functions. Grimberg,[17] in a similar vein, discusses the need for promptness, dependability, brevity, perspicuity, and discriminability in military information systems and displays, and infers that any symbolic or graphic system should be evaluated on these factors.

A number of agencies besides TCATA have strongly advocated the development of new tactical symbols for automated graphic displays. For example, Colanto,[18] in a paper given at the Computer Graphics Symposium

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[15] S. Ringel, F. L. Vicino, and R. S. Andrews. *Human Factors Research in Command Information Processing Systems,* Technical Research Report 1145, US Army Personnel Research Office, March 1966.

[16] H. M. Parsons and W. E. Perry. *Concepts for Command and Control Systems,* Systems Development Corporation, Falls Church, Virginia, December 1965.

[17] J. C. Grimberg. *A Parametric Approach to the Evaluation of Military Information Systems,* Bunker-Ramo Corporation, McLean, Virginia, June 1966.

[18] J. Colanto. "Experimental Combat Power Symbology Related to Intelligence Preparation of the Battlefield," paper presented at *Symposium on Computer Graphics in Support of Tactical Command and Control,* Headquarters, TRADOC Combined Arms Test Activity (TCATA), Fort Hood, Texas, August 1977.

at Fort Hood in 1977, presented a method of conveying combat power to a corps commander in a simplistic and symbolic manner. Earlier, Sidorsky[19] indicated that the Army Research Institute (ARI) was interested in such facilities as CCIDES and their potential benefits in the development of such techniques as Combat Power Symbology (CPS). However, he does list 18 competing/conflicting design requirements for such displays. For example, "The need to provide an overview of area of interest" conflicts with "Need to resolve small details (terrain, location, line of sight, defiles, etc)." Wilmot [20] described the experimental development of a supplemental and adjunct symbology termed DIVRAS. This system, among other uses, would allow a terminal operator to superimpose a simplified potential threat overlay on map backgrounds of varying detail without affecting other overlays.

In addition, other symbologies, such as the current Soviet symbology, NATO STANAG 2019, and symbologies suggested by ARI, have been proposed for evaluation with CCIDES using performance-oriented techniques. The results of these evaluations would also be employed to further develop and refine procedures for comparing and assessing the utility of various symbology sets in tactical scenarios.

To summarize, there is general agreement that a new symbology is needed for use with computer-generated graphic tactical displays. However, there is far less agreement on exactly what kind of symbol set is needed. This is undoubtedly one of the major reasons why, some 25 years after the technology was available, the Army has still not yet procured an operational system.

The remainder of this report will consist of three chapters. Chapter 2 provides a review of literature on display techniques. The advantages and problems inherent in the use of various coding systems are discussed; i.e., geometric, color, flash rate, and alphanumerics. A section of Chapter 2 is also devoted to review of studies dealing with symbol size and proportion. Chapter 3 describes a study of preferences among four symbol sets. Respondents were requested to select the best representation for each of several different kinds of units or functions. Chapter 4 presents a brief summary, and provides suggestions for future research.

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[19] R. C. Sidorsky. "Development of Combat Power Symbology," letter to LTC R. B. Webb, US Army Intelligence Center and School, Fort Huachuca, Arizona, from US Army Research Institute for the Behavioral and Social Sciences, Arlington, Virginia, March 1976.

[20] R. W. Wilmot. "Considerations in the Development of DIVRAS Symbology," paper presented at *Symposium on Computer Graphics in Support of Tactical Command and Control*, Headquarters, TRADOC Combined Arms Test Activity (TCATA), Fort Hood, Texas, August 1977.

Chapter 2

REVIEW OF THE LITERATURE

The CCIDES facility at TCATA, as a representative of the type of interactive graphic display equipment and technology currently available for use in Tactical Operations Systems (TOS), has a four-color graphic and alphanumeric dynamic display capability with flash-rate coding available if desired, in addition to the static digitized map display capability.

Therefore, review of studies will be limited to the areas of graphic (shape) coding, color coding, alphanumerics, and flash-rate coding. The graphic symbols currently used by CCIDES are the standard military symbols found in FM 21-30[1] and FM 21-31.[2]

These symbols are based on their supposed iconic representation of unit function, equipment, or activity. However, there is little empirical evidence that all of these symbols have particularly high association values to the concept, function, or equipment symbolized, or that they convey sufficient information for optimal decision-making by the user.

Graphic Coding

Graphic or symbolic coding makes information available immediately and directly to the user, allowing for improved efficiency and reducing errors. This review will focus on the areas which appear to bear most directly on the methods and problems associated with computer-generated displays and human information processing.

Barmack and Sinaiko[3] list 12 graphic coding methods which have been used in studies utilizing (or applicable to) computer-generated graphic displays. Honigfeld[4] lists 13 to 16 methods used in radar symbology

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[1] US Department of the Army. Field Manual 21-30, "Military Symbols," 1970.

[2] US Department of the Army. Field Manual 21-31, "Topographic Symbols," 1968 (update of 1961 version).

[3] J. E. Barmack and H. W. Sinaiko. *Human Factors Problems in Computer-Generated Graphic Displays*, Research and Engineering Support Division, Institute for Defense Analysis, Washington, D.C., April 1966.

[4] A. R. Honigfeld. *Radar Symbology: A Literature Review*, Technical Memorandum 14-64, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, September 1964.

studies. Most human engineering guides list from 10 to 12 common visual coding methods, which they rate from excellent to poor in terms of coding effectiveness. Those rated as excellent to fair include: geometrics, color, alphanumerics, line length, clock coding, inclination, numerosity, and combinations of the foregoing. Flicker, brightness, ellipse, and diameter coding are generally rated poor.

The CCIDES facility at TCATA, as a representative of the type of interactive graphic display equipment and technology currently available for use in Tactical Operations Systems (TOS), has a four-color graphic and alphanumeric dynamic display capability with flash-rate coding.

Historical Development of Graphic Symbologies

While much of the literature reviewed in this section is academic and not always directly relevant to the current symbology utilized by such facilities as CCIDES, this information is important to consider as a guide in the development of alternative symbologies.

Interest in graphic symbologies began many centuries ago when man first began to develop language and used wall markings and chipping to leave messages for others of the tribe.[5] The development of hieroglyphics, signs, and actual alphabets followed by many paths, depending on clan or tribal requirements and various environmental factors.[6]

Formal research on geometric or shape coding appears to have originated with the early psychologists who were interested in perceptual processes and the nature of learning and memory. Early researchers, such as Stevens,[7] Geissler,[8] and Kleitman and Blier,[9] were concerned

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[5] L. M. Biberman (ed.). *Perception of Displayed Information*, New York: Plenum Press, 1973.

[6] G. Kepes (ed.). *Sign, Image, Symbol*, New York: Brazziller, 1966.

[7] H. C. Stevens. "The Peculiarities of Peripheral Vision," *Psychological Review*, 1908, 5(2), 69-63.

[8] L. R. Geissler. "Form Perception on Indirect Vision," *Psychological Bulletin*, 1926, 23, 135-136.

[9] N. Kleitman and A. Z. Blier. "Color and Form Discrimination in the Periphery of the Retina," *American Journal of Physiology*, 1928, 85, 178-190.

primarily with peripheral phenomena, such as accuracy of perception and reproducibility of form and color when not viewed foveally. Their findings aroused further interest in all areas of visual research, and after Koffka's[10] text on Gestalt Psychology appeared in 1935, there was considerable activity to examine and attempt to prove or disprove his principles of the perception process. Honigfeld[11] presents an excellent brief review of the Gestalt theories of pattern perception. Briefly, these claim that the circle is the "perfect" figure, that figure has predominance over ground, that simplicity and symmetry guide recognition, and that color is associated with shape. In opposition to Gestalt principles, many investigators[12,13,14,15] demonstrated that triangles, rectangles or crosses were superior to circles in threshold perception and/or peripheral detection. The "Principle of Pragnanz," Koffka's statement of the characteristics of the "best" figures or shapes according to his theories, came under particularly heavy attack. The issue remains unresolved. Fehrer,[16] in 1935, found that simple symmetric figures were most easily learned, and Woodworth and Schlosberg[17] emphasized the virtue of symmetry as did Attneave[18] and others. Fitts, et al.[19] found that their subjects were somewhat more accurate in learn-

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[10] K. Koffka. *Principles of Gestalt Psychology*, New York: Harcout, Brace and Company, 1935.

[11] Honigfeld, *op. cit.*

[12] R. M. Collier. "An Experimental Study of Form Perception in Indirect Vision," *Journal of Comparative Psychology*, 1931, 2(3), 281-290.

[13] C. A. Whitmer. "Peripheral Form Discrimination Under Dark-Adaptation," *Journal of General Psychology*, 1933, 9, 405-419.

[14] H. King, C. Landis, and J. Zubin. "Visual Subliminal Perception Where Figure is Obscured by the Illumination of the Ground, *Journal of Experimental Psychology*, 1944, 34, 60-69.

[15] R. C. Casperson. "The Visual Discrimination of Geometric Forms," *Journal of Experimental Psychology*, 1950, 40, 668-681.

[16] E. V. Fehrer. "An Investigation of the Learning of Visually Perceived Forms," *American Journal of Psychology*, 1935, 47(2), 187-221.

[17] R. S. Woodworth and H. Schlosberg. *Experimental Psychology* (rev. ed.), New York: Holt Company, 1954.

[18] F. Attneave. "Physical Determinants of Judged Complexity of Shapes," *Journal of Experimental Psychology*, 1957, 53(4), 221-227.

[19] P. M. Fitts, M. Weinstein, M. Rappaport, N. Anderson, and J. A. Leonard. "Stimulus Correlates of Visual Pattern Recognition: A Probability Approach," *Journal of Experimental Psychology*, 1956, 51, 1-11.

ing (and identifying) those symbols which were symmetrical around the vertical axis than those symmetrical around the horizontal axis. Attneave also found that subjects' ratings of the simplicity of forms was based primarily on the number of turns in the contour and their sharpness and symmetry. Dardano and Donley[20] found that complete figures (i.e., circles) were more discriminable than incomplete figures (i.e., 1/2 circles). Gaito[21] reported that there is a much greater tendency for curved lines to be perceived as straight lines than for straight lines to be seen as curved; however, a single curved line is more easily perceived than two or three straight lines. Rappaport[22] was not able to verify his hypothesis that presenting complex symmetrical figures would allow better performance than presenting equally complex assymmetrical figures. Deese[23] found that when subjects needed to remember only one shape at a time, complex figures were more accurately discriminated than simpler shapes.

Perceptual thresholds are influenced to some extent by the shape of the form presented. For example, Collier,[24] presented seven different forms peripherally, and found the recognition of equilateral and isosceles triangles greatly superior (significantly lower threshold) to that of squares, parallelograms, circles, hexagons, and octogons. However, the details of the design and subject response requirements were not clearly reported, making the interpretation of Collier's findings difficult. However, Kleitman and Blier,[25] in a threshold study used solid black forms of equal area on a white background which were presented both centrally and peripherally. Kleitman and Blier found the triangle more readily recognized than circles, stars or squares for both presentation conditions. Munn and Geil[26] also presented forms of equal area viewed peripherally and found the triangle most readily recognized over

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[20] J. F. Dardano and R. Donley. *Evaluation of Radar Symbols for Target Identification*, Technical Memorandum 2-58, US Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, March 1958.

[21] J. Gaito. "Visual Discrimination of Straight and Curved Lines," *American Journal of Psychology*, 1959, 72, 236-242.

[22] M. Rappaport. "The Role of Redundancy in the Discrimination of Visual Forms," *Journal of Experimental Psychology*, 1957, 53(1), 3-10.

[23] J. Deese. *Complexity of Contour in the Recognition of Visual Form*, Technical Report 56-60, Wright Air Development Center, Wright-Patterson AFB, Ohio, 1956.

[24] Collier, *op. cit.*

[25] Kleitman and Blier, *op. cit.*

[26] N. L. Munn and G. M. Geil. "A Note on Peripheral Form Discrimination," *Journal of General Psychology*, 1931, 5, 78-88.

the greatest parametric field. Helson and Fehrer[27] used six forms equal in area composed of black figures on white backgrounds and found that triangles and rectangles had the lowest recognition thresholds. Witmer,[28] in a similar study, found the percentage of correct discrimination of triangles highest, followed by diamonds, squares, rectangles, circles and hexagons. King, et al.[29] conducted a subliminal (forced guess) study and found that while performance on the triangle was best, all three figures (triangles, circles, and squares) were perceived at above-chance levels.

A common problem of the foregoing studies is that the use of different forms leaves the triangle as the only shape without an obvious confusion form, such as square-rectangle, star-cross, circle-hexagon. Hochberg, et al.,[30] using a somewhat different approach in an attempt to control for background-figure interaction and frame effects, projected circles, squares and St. Andrews crosses equal in area as bright forms on a dark screen. The circle required the lowest light level for perception, while the St. Andrews cross required the most, in contrast with the other equal-area studies. Hochberg, et al. reported that visual angle subtended was inversely related to perception. Hanes[31] argues that the triangle may give lower thresholds, but that above threshold values triangles may not be most rapidly recognized. Hanes used circles, triangles, and squares, each with three different areas (0.0031, 0.01230, and 0.17854 square inches) subtending visual angles of 9, 19, and 144 minutes of arc at 24 inches. Subjects were required to match the brightness of the three shapes to a .1 millilambert (ml) standard. For the two smaller areas (9 and 19 minutes) the triangle was matched best (.095 ml) and square worst (.125 ml). For the 144 minute shapes, performance was best with the circle. Hanes stated that these results were a function of the interaction of shape with luminance level.

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[27] H. Helson and E. V. Fehrer. "The Role of Form in Perception," *American Journal of Psychology*, 1932, 44, 79-102.

[28] Witmer, *op. cit.*

[29] King, Landis, and Zubin, *op. cit.*

[30] J. E. Hochberg, H. Gleitman, and P. D. McBride. "Visual Threshold as a Function of Simplicity of Form," *American Psychologist*, 1948, 3, 341-342.

[31] R. M. Hanes. "Some Effects of Shape on Apparent Brightness," *Journal of Experimental Psychology*, 1950, 40, 650-654.

While the studies just discussed used rather limited "alphabets" (six or less figures) and concluded in general that triangles were superior to circles (at least in threshold studies), this is in contradiction to the Gestalt theory. Other studies, using larger alphabets, still have not answered all the questions concerning what characteristics make up the "best" figures. Casperson[32] conducted an elaborate study to determine the discriminability thresholds of six different geometric forms. A secondary goal of Casperson's research was to relate these thresholds to three quantifiable aspects--area of the figure, maximum dimension, and perimeter. For each of the six figures, area was held constant at seven different values, and within each value, maximum dimension and perimeter was varied. Subjects judged the resulting six complete figures as rapidly and accurately as possible. Circles and ellipses were the most difficult to discriminate; area was the best measure of discrimination of ellipses and triangles; maximum dimension was the best discriminator for rectangles and diamonds; perimeter was best for stars and crosses. Overall, the best discriminator was maximum dimension, with best performance on the triangle, rectangle and cross.

Sleight[33] looked at the relative discriminability of different geometric forms presented in a complex panorama, much as might be found on a TOC display. Unfortunately, the task was rather artificial; the stimuli were six each of 21 different geometric forms constructed of black paper and mounted on 14 inch clear lucite squates, then randomly displayed on a 25 inch circle display background. The task was to sort all six of a particular form into a separate compartment as quickly and accurately as possible, disregarding the remaining 120 forms. Most quickly sorted were the swastika, circle, crescent, airplane, cross, and star, in that order.

Bitterman and Krauskopf[34] conducted a series of studies to examine the implications of the Kohler-Wallach theory of figural after-effect diffusion (corners tend to round off, gaps close, fine detail blurs). They found that luminance required for detection correlated highly with the ratio of perimeter to area. Circles were rarely confused with anything, but squares and triangles were confused with circles, crosses and Xs with diamonds, Is with inverted triangles, Ls with semicircles,

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[32] Casperson, *op. cit.*

[33] R. B. Sleight. "The Relative Discriminability of Several Geometric Forms," *Journal of Applied Psychology*, 1948, 32, 170-188.

[34] M. E. Bitterman and J. Krauskopf. *Some Determinants of the Threshold for Visual Form*, Technical Report 53-331, Wright Air Development Center, Wright-Patterson AFB, Ohio, September 1953.

and Hs with butterflies. Recognition thresholds varied inversely with exposure time, with area, and with amount of critical detail. Brightness thresholds varied inversely with exposure time and area, but were relatively unaffected by extensive changes in configuration.

Bowen, et al.[35] surveyed the literature in 1959 and found no definitive rules for constructing easily recognizable symbols for radar displays. These authors, therefore, attempted to find the rank-order discriminability of a set of 20 geometric symbols. Using varying degrees of degradation by noise, distortion and blur, they established subsets which would yield minimal confusion of forms. Increasing distortion and noise lowered performance significantly, but increasing blur alone did not. Ten symbols were found that were highly discriminable from one another under "good" conditions. However, it was recommended that no more than six be used under adverse conditions. A second experiment was conducted to determine optimal form size and stroke-width to height ratio. The stimulus set consisted of a circle, cross, triangle and square. Each symbol was presented with three stroke width-to-height ratios (1:6, 1:8, and 1:10), and in three sizes (.25, .375 and .5 inches). Nine different formats were thus generated for each symbol. Each symbol appeared 20 times. Subjects were asked to count the occurrences of a given figure as quickly and as accurately as possible. The cross was best recognized in all three sizes, the triangle worst. The largest figures (.5 inches) were counted fastest; however, stroke width-to-height ratio had no effect on counting speed. With the two smaller figures, the higher (1:8 and 1:10) stroke-width-to-height ratios were better. The authors concluded that:

1. Symbols should subtend a minimum of 20 minutes of arc at close viewing distances (28 inches), and about 22 minutes at greater distances.

2. The stroke width-to-height ratio should be 1:8 or 1:10 for symbols .4 inch or larger when viewed at distances up to 7 feet.

3. The highest counting rate was about .7 seconds per symbol.

Williams and Falzon[36] investigated discrimination and search time with 100 symbols presented in five 10 x 10 matrices, in either ordered or staggered arrangements. Each symbol was projected for .5 seconds and viewed either at 45° to the left, at the vertical midline, or at 45° to

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[35] H. M. Bowen, J. Andreassi, S. Truax and J. Orlansky. *Optimum Symbols for Radar Displays*, ONR-0682(00), Office of Naval Research, Washington, D.C., September 1959.

[36] J. R. Williams and R. P. Falzon. "Relationship of Some Display System Variables to Symbol Recognition and Search Time," *Journal of Engineering Psychology*, July 1963, 2(3), 97-111.

the right. Each symbol subtended 20 minutes of arc. Arrangement of the matrices had no effect on performance, but viewing angle had a highly significant effect on accuracy but not on search time. In a second experiment by Williams and Falzon,[37] 25 outline geometric shapes, each subtending 10 minutes of arc, appeared for .5 second per presentation. The shapes were often flanked by irrelevant lines. Flanked diamonds were poorly recognized and often were confused with other shapes, while best performance was observed with squares and circles. Recognition accuracy with triangles was below that with squares and circles but better than that with diamonds.

Technological advancements have extended the scope of interest in symbology beyond these limited and rather artificial studies which used preselected, arbitrary, and usually small symbol sets. Computer-generated video has provided the capability for transforming the traditional table-top or transparent wall display into a meaningful picture of action with targets clearly presented. Map overlays, terrain features, updated movements, and other items of interest can be displayed on demand. However, such unlimited freedom to create new and larger symbol sets can have unfortunate consequences. Semple, et al.[38] point out, even the best "producer" may become tempted to overload "subjects" by adding excessively to the symbol set vocabulary.

Applied Research in Graphic Symbology

Honigfeld,[39] in 1964, and Davis,[40] in 1969, reviewed the state-of-the-art in radar symbology. Both reviewers alluded to a dearth of research aimed at developing a complete and versatile shape coding system. Much the same can be said for the current Army symbology which utilizes graphics on computer-generated tactical operations displays.

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[37] J. R. Williams and R. P. Falzon. "Comparison of Search Time and Accuracy Among Selected Outlined Geometric Forms," *Journal of Engineering Psychology*, July 1963, 2(3), 112-118.

[38] C. A. Semple, Jr., R. J. Heapy, E. J. Conway, Jr., and K. T. Burnette. *Analysis of Human Factors Data for Electronic Flight Display Systems*, AFFDL-TR-70-174, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, April 1971.

[39] Honigfeld, *op. cit.*

[40] S. Davis. *Computer Data Display*, Englewood Cliffs, New Jersey: Prentice-Hall, 1969.

Vicino, et al.[41] conducted a study which is directly applicable to the types of tasks which might be performed on a TOC system. Two sets of slides were prepared. Either 12, 18, or 24 military symbols were randomly displayed on Map Set I. Set II was identical to Set I except that either 2, 4, or 6 symbols had been added, removed or repositioned. Each of 48 subjects was shown a slide from Set I and asked to count and identify the unit symbols displayed (half of which were infantry, a quarter artillery, one-sixth air defense, and one-twelfth engineer units). The subject was then briefly shown the corresponding slide from Set II and, on a scaled-down paper print of the first slide, asked to note what changes had occurred. The control group had no aids of any sort, while the three experimental groups were given either a hard copy of Set II, shown a slide of Set II containing a single-cue code (N for new, M for moved, R for removed), or a slide of Set II containing a double-cue code (double lines around changed units, as well as the letter code). Each subject's assimilation score was determined by the percentage of the changes he recorded correctly on his copy of Set I. It was found that: (a) Increasing either the amount of information presented or the amount of updating resulted in decreased performance. Double-cue coding completely eliminated performance decrement due to increased amount of information. (b) Double-cue coding improved extraction scores (number of changes correctly noted divided by total response time, times 100) by 97%, and assimilation scores (number of changes correctly noted divided by this same number plus errors of commission plus errors of omission, times 100) by 57% over unaided performance. Single-cue coding resulted in a 68% and 47% improvement, respectively. Providing hard copy failed to improve extraction at all, and improved assimilation only slightly. (c) Both extraction and assimilation scores were highest when symbols had been removed, and lowest when symbols had been repositioned. (d) As the number of changes was increased, errors of omission increased more rapidly than errors of commission. The authors concluded that operators watching displays characterized by frequent or drastic updating need much better methods of keeping track of changes than were currently (1965) available.

Vicino and Ringel[42] conducted a study using slides instead of video presentations in which 37 subjects viewed a series of military situations. The subjects were to determine in which of three sections the enemy was forming fastest for attack and which showed the most appropriate disposition of forces. The development of each situation was

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[41] F. L. Vicino, R. S. Andrews, and S. Ringel. *Conspicuity Coding of Updated Symbolic Information*, Technical Research Note 152, Support System Research Laboratory, US Army Personnel Research Office, May 1965.

[42] F. L. Vicino and S. Ringel. *Decision Making with Updated Graphic vs Alpha-Numeric Information*, Technical Research Note 178, US Army Personnel Research Office, November 1965.

depicted in either 7 or 14 slides, and the data on the sides were either in graphic or in alphanumeric form. The results were rather inconclusive. No differences were found as a function of updating rate nor between the graphic and alphanumeric formats. However, subjects did show a greater shift in confidence in their responses from slide to slide in the 7-slide condition. Also, regardless of the condition of presentation, correct final decisions tended to occur about three-quarters of the way through the series.

Kolers[43] considered the the claim of "immediacy" or "directness") of association for pictograms as being false. He pointed out that the meaning attached to or conveyed by a pictorial or outline representation of an object, concept, or event may not be the one intended. Symbols may have different meanings for different observers, depending upon their background, experience, and training.[44] Koler's discussion reveals two basic problems which must be addressed in desiOning (or learning) any coding systems: (a) care must be taken to minimize the possibility of confusion based upon preexisting meanings, and (b) intersymbol confusion must be avoided.

Howell and Fuchs[45] conducted six studies of population stereotypes of concepts and symbols that reflect those stereotypes. Howell and Fuchs had 20 college students each construct five different drawings of each of 52 military concepts supplied by the Air Force. The 100 drawings for each concept were evaluated and summarized by three judges into the six most common symbols for each concept. Then 20 new subjects were used to rank order the six symbols for applicability to its concept. Next, 50 additional subjects rated the symbols on simplicity, pictorial quality, pleasantness, meaningfulness, and familiarity. All measures obtained were subjected to factor analysis. The major factor, which they labeled "population stereotype," was primarily determined by the applicability rank score, which the experimenters chose to use in the remainder of their studies.

In a second experiment, Howell and Fuchs presented 20 naive subjects with the list of concepts and asked them to match, one at a time in random order, the 52 symbols with the highest "applicability" scores and the 52 symbols with the lowest "applicability" scores to the most appropriate concept. Results showed that the symbols, in general, were

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[43] P. A. Kolers. "Some Formal Characteristics of Pictograms," *American Scientist*, 1969, 57, 348-363.

[44] W. C. Howell and A. H. Fuchs. *The Study of Graphic Language*, RADC-TR-61-76, Ohio State University, October 1961.

[45] *Ibid.*

assigned correctly at a significantly higher than chance level and that the high "applicability" symbols were assigned correctly significantly more often than the low applicability symbols.

Howell and Fuchs then examined ease of learning and recognition of these graphic symbols and a two-digit code. Three groups of subjects, nine per group, learned either a high applicability score symbol set, a low applicability score symbol set, or the number code for the 52 concepts to a criterion of 100%. The high applicability score symbol set was learned significantly faster (fewer trials) than either of the other sets. All subjects were then tested under short exposure (.3 seconds or less) and accuracy and latency scores recorded. The high applicability score symbol set was again significantly better than the other two codes on latency scores, but no significant differences were obtained on accuracy scores.

In Experiment V, 12 subjects (four per group) learned either the high applicability score symbols, or the word, or the initial letter code for each concept, again to the 100% criterion level. All subjects were then tested under eight conditions: blurred versus sharp focus by 0°, 90°, 180°, or 270° rotation (all learning trials were under the sharp focus, upright condition). Using a .04 second exposure, latency and accuracy scores were obtained for all subjects and conditions. No significant differences were found between the sharp upright condition and the other conditions, but the high stereotype score symbols showed significantly less degradation in both scores under all seven other conditions than did the other two codes.

In Experiment VI, the final test of Howell and Fuchs' "highly stereotypic symbols," 10 subjects learned 14 of the high applicability score symbols and 14 "nonsense" forms; another 10 subjects learned 14 military symbols and 14 nonsense forms for the same 28 concepts, then tested for recognition (latency and accuracy scores). The high applicability symbols were learned significantly faster than the military symbols, but although differences in accuracy and latency scores favored the high applicability symbols, they did not attain significance. Both the high applicability and the military symbols were significantly better than the nonsense forms on all measures.

Their conclusions from this extensive set of studies were that highly stereotypic graphic symbols are learned in less time and are recognized with fewer errors, even under degradation, than other, less stereotypic graphic symbols. They recommend that, given a vocabulary (symbol set) of concepts, it should be determined (a) who will use them, (b) the operations for which the symbols will be used, and (c) the viewing conditions.

Color Coding

Recently, an increase has been seen in investigations of the use of color in coding information. This phenomenon may be due to the increasing reliance on computer-generated display systems, and the emergence of other systems with complete color capability. Yet, the human is still the primary analyst of the information presented in a display. Even under optimal conditions, the amount of information or stimulation that the human can assimilate in a given period of time rather quickly reaches aymptote. As Miller[46] points out, the human channel capacity is rather small, and varying a single attribute of a coding system (such as shape) can increase the amount of transmitted information only to certain limits. Due to this limitation, adding another dimension, such as color, offers considerable promise in more complex displays.

However, many aspects of color must be investigated before it can be used optimally in visual displays. Some of these are brightness, area, nature of the light source, and the interactive effect of colors and symbols. The nature of the operator's task must also be carefully weighed. There are also definite limitations on the usefulness of multidimensional and combinatorial codes.

Luxenberg and Kuehn[47] point out that aperture color (color without form) has three physical dimensions; brightness, hue, and saturation. With the other two parameters held constant, the ability of humans to detect hue (wavelength) shows a great deal of individual variation. Osgood[48] lists four spectral regions around which maximal differential sensitivity occur: 440λ[49] (blue), 485λ (green), 575λ (yellow), and 640λ (red). Object colors (i.e., color with form) have the additional properties of reflectance, volume, form, transmittance, etc. These dimensions of object color are only indirectly relevant to color displayed two-dimensionally on cathode ray tubes.

Rather than attempt to cover the immense number and variety of studies involving color, this review will concentrate primarily on those aspects most relevant to the use of color coding on computer displays:

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[46] G. A. Miller. "The Magic Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," *Psychological Review*, 1956, 63, 81-97.

[47] H. R. Luxenberg and R. L. Kuehn. *Display System Engineering*, New York: McGraw-Hill Book Company, 1968.

[48] C. E. Osgood. *Method and Theory in Experimental Psychology*, Fair Lawn, New Jersey: Oxford University Press, 1953.

[49] λ = millimicrons = μ = wavelength.

hue alphabet size (number of absolutely discriminable colors under reasonable operating conditions), studies showing the advantages of color-coding, and studies showing the disadvantages.

In composing a display-oriented color alphabet, most experimenters avoid relative judgment or comparisons, and allow only absolute judgments. Experimenters have found[50,51] that subjects can make from 128 to 150 comparative stimulus hue discriminations, but absolute discriminations appear to be limited to, at best, 10 hues.[52,53,54,55]

Conover and Kraft,[56] and Conover,[57] working with surface colors, found that, depending upon the subject, the number of absolutely discriminable hues varied from 5 to 16. They recommended that nine be the maximum number of colors used in displays, and only eight if discriminations are to be made on the basis of hue alone. They further suggested that if colors are likely to become desaturated, self-luminous

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[50] W. D. Wright. "The Sensitivity of the Eye to Small Color Differences," *Proceedings of the Physical Society of London*, 1941, 53, 93-112.

[51] J. W. Wulfeck, A. Weisz, and M. Ruben. *Vision in Military Aviation*, WADC-TR-58-399, Wright Air Development Center, Air Research and Development Command, Wright-Patterson AFB, Ohio, November 1958.

[52] C. D. Baker and W. F. Grether. *Visual Presentation of Information*, WADC-TR-54-160, Wright Air Development Center, Wright-Patterson AFB, Ohio, August 1954.

[53] R. M. Halsey and A. Chapanis. "On the Number of Absolutely Identifiable Hues," *Journal of the Optical Society of America*, 1951, 14(12), 1057-1058.

[54] C. T. Morgan, et al. *Human Engineering Guide to Equipment Design*, New York: McGraw-Hill Book Company, 1963.

[55] P. F. Muller, R. C. Sidorsky, A. J. Slivinske, E. A. Alluisi, and P. M. Fitts. *The Symbolic Coding of Information on Cathode Ray Tubes and Similar Displays*, WADC-TR-55-375, Aeromedical Laboratory, Wright Air Development Center, Wright-Patterson AFB, Ohio, October 1955.

[56] D. W. Conover and C. L. Kraft. *The Use of Color in Coding Displays*, WADC-TR-55-471, Wright Air Development Center, Wright-Patterson AFB, Ohio, October 1958.

[57] D. W. Conover. *The Amount of Information in the Absolute Judgment of Munsell Hues*, WADC-TN-58-262, Wright Air Development Center, Wright-Patterson AFB, Ohio, June 1969.

hues should be used. The number of self-luminous hues used should not exceed six, and only five should be used under degraded viewing conditions.

Morgan, et al.[58] made the following recommendations for color coding targets against a non-uniform background:

1. Choose a color that contrasts most with the colors in the background.

2. Choose a brightness that differs as much as possible from the background (bright on dark, or vice versa).

3. Use a fluorescent color for targets against a dark background.

4. Use as large an area of solid color as possible. Do not use stripes or checks, as they fuse and reduce contrast.

5. If targets must be viewed against a variety of backgrounds, targets can be coded in two contrasting colors, dividing targets into two large areas of solid color. Good pairs of colors to use are: white and red, bright yellow and black, bright yellow and blue, or bright green and red.

6. If color is not available as a coding device, additional information can be presented by use of the three discriminable achromatic colors; white, grey and black.

Some of the advantages (and disadvantages) of color coding are discussed in detail in an excellent review article by Christ.[59] Major advantages appear to be that color codes, redundant or non-redundant, are useful for locating or attention-getting. However, for identification tasks, color is less efficacious than other coding devices. Human performance is usually enhanced when color is combined with other coding methods (alphanumeric or geometric shape) with either partial or complete redundancy. The use of color does provide an additional dimension for the presentation of information and, for most of the population, provides basic qualitative categories requiring little additional training.

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[58] Morgan, et al., *op. cit.*

[59] R. E. Christ. "Review and Analysis of Color Coding Research for Visual Displays," *Human Factors*, 1975, 17(6), 542-570.

Eriksen[60,61,62] explored the speed with which various targets could be located in a visual display. Two basic sorts of target objects were presented:

1. Seven classes of objects were displayed (circles, hexagons, etc.; see Table 2-1) which differed on either hue, brightness, size or form. Only one dimension was varied on each object.

2. Ten objects were used which differed on two or three of these dimensions.

Table 2-1 lists the values of the dimensions used in these experiments.

Table 2-1. Classes of Objects Used Within the Four Dimensions (After Eriksen*)

Object Class	Hue**	Form	Brightness**	Size (inches)
1	R 5/6	Circles	N 1/	.5
2	YR 5/6	Hexagons	N 7/	.625
3	Y 5/6	Diamonds	N16/	.75
4	GY 5/6	Triangles	N15/	.875
5	G 5/6	Crosses	N 4/	1.0
6	BG 5/6	Stars	N 3/	1.125
7	B 5/6	Squares	N 2/	1.25

*C. W. Eriksen. "Location of Objects in a Visual Displays as a Function of the Number of Dimensions on Which the Objects Differ," *Journal of Experimental Psychology*, 1952, 44(1), 55-60.
**Munsell notation.

The targets produced by varying two or more dimensions in combination were not detected faster than the targets based on varying a single

[60] C. W. Eriksen. "Location of Objects in a Visual Display as a Function of the Number of Dimensions on Which the Objects Differ," *Journal of Experimental Psychology*, 1952, 44(1), 55-60.

[61] C. W. Eriksen. *Multidemensional Stimulus Differences and Accuracy of Discrimination*, WADC-TR-54-165, Wright Air Development Center, Wright-Patterson AFB, Ohio, June 1954.

[62] C. W. Eriksen. "Object Location in a Complex Perceptual Field," *Journal of Experimental Psychology*, 1953, 45, 126-132.

dimension. However, targets in which hue and form were varied were detected slightly faster (.652 to .678 mean log time) than any of the targets which varied on only a single dimension. All other combination targets resulted in slower responses than the single dimension targets. When a single dimension was varied, changing hue resulted in the best performance, and changing form was the next most effective.

Cohen and Senders[63] conducted an experiment to determine whether shape or color coding was more efficient in reducing search time and errors in locating dials on visual displays. Each of 29 subjects viewed banks of dials mounted on white backgrounds. The dials featured white pointers on a black face. A half-inch wide geometric shape around each dial provided either color or shape coding for that dial. An initial learning period was followed by five days of practice, one day off, and a final relearning period. Cohen and Senders found that color coding was significantly more helpful than shape coding during both learning and relearning.

Hitt[64] conducted a study to evaluate five different abstract coding methods for their effects on the performance of various operator tasks. Operators were required to count, identify, locate, compare, or verify the existence of certain target symbols. In this experiment five different symbol types or codes (numerals, letters, geometric shapes, colors, and configurations[65]) were used. The number of levels per code type varied from 2 to 8, and target density varied from 40 to 80 to 120 symbols per display. For each of the five code types, nine displays were prepared (code type x three density levels x three code levels). The five subjects were trained to criterion on the meaning associated with each symbol level, then tested on the 224 conditions. The entire procedure was repeated for another set of five subjects to cross-validate the results, with a correlation of .97. Results showed that color was significantly superior for the location task, number significantly superior for identification (with color poorest), and number best with color second on the other three tasks. Increase in number of code levels and/or target density degraded operator performance for all code types.

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[63] J. Cohen and V. Senders. *An Experiment on Dial Coding*, Technical Report 52-509, Wright Air Development Center, Wright-Patterson AFB, Ohio, November 1953.

[64] W. D. Hitt. "An Evaluation of Five Different Abstract Coding Methods," *Human Factors*, July 1961, 3(2), 120-130.

[65] Configurations were 2 x 2 matrices with one or more of the cells occupied.

Anderson and Pitts,[66] using two subjects, studied the amount of information a subject could report from a tachistoscopic presentation of letters and numerals. Variables were information content and coding format. Information content varied from an average of 6.34 bits for minimum length messages to 19.02 bits for the maximum length messages. Coding formats were alphanumeric alone or a combination of alphanumerics and color. Results showed that performance was vastly superior for the color-alphanumeric combination than with either alone. A replication with two new subjects confirmed these results.

Promisel[67] investigated the effect of varying the number and nature of non-target objects in a display with both partially and fully redundant codes. Targets were identified by hue-form combinations amid varying levels of competing and non-competing clutter, where competing clutter was of the same hue or shape as the target. Predictably, color facilitated search time, and color identity of targets and non-targets provided more interference than shape identity. Moreover, search-task behavior seemed determined by the interaction of the number of competing non-targets with the kind of non-targets. Search time was determined by both shape and hue with few competing non-targets, but with large numbers of competing non-targets, search time appeared to be determined by only one of the two, depending upon a subject's preference for shape or color in searching for the target.

Smith[68] proposed that visual search time is a fundamental measure of the potential value of color coding of displays. Accordingly, Smith presented his subjects with targets consisting of one of five possible letters, three numerals, and a vector. Either 20, 60, or 100 items appeared in each of 180 displays, with half the displays in black and white, and the other half in colors. The five colors used were redundant with the five class-designator letters. The 12 subjects either searched for a particular target or counted the number of a particular class. As might be expected, both search time and counting errors increased with increasing density. Color had no effect if the subject was ignorant of its relevance. However, informing subjects in advance of the redundancy of color and letter codes resulted in a 65% reduction in search time, a 69% reduction in counting time, and a 76% reduction in counting errors.

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[66] N. S. Anderson and P. M. Pitts. "Amount of Information Gained During Brief Exposures of Letters and Numerals," *Journal of Experimental Psychology*, 1958, 56(4), 367-369.

[67] D. M. Promisel. "Visual Target Location as a Function of the Number and Kinds of Competing Signals," *Journal of Applied Psychology*, 1951, 45(6), 420-427.

[68] S. L. Smith. "Color Coding and Visual Search," *Journal of Experimental Psychology*, 1962, 64, 434-440.

Jones[69] concluded that search time is decreased by the concomitant use of a partially or fully redundant color code of which the subject was aware and was inversely proportional to the number of colors used at a given density level.

Smith and Thomas[70] systematically measured the apparent superiority of color coding by comparing it to various shape codes in a relatively simple situation: counting the instances of a particular class of item within a display. Either 20, 60, or 100 symbols on a dark background appeared on each of 45 slides. Subjects analyzed each display 10 times, once for each possible shape (five) and once for each possible color (five). A second set of 15 100-item slides were presented to examine the effect of shape coding when color did not vary. A third set of slides contained one military symbol 100 times in the five colors. This set was used to study the effect of color on shape coding. Colors were counted twice as rapidly as was the best set of shape symbols, and three times as fast as was the poorest set of shape symbols. Fewer errors were made in counting colored figures and at lower densities. Statistical analyses indicated that differences in counting time were attributable to display density, shape code, counting code (color or shape), and their interaction. The authors did not attempt to explain the interactions, but stated that some combinations apparently were effective in enhancing counting performance.

Munns[71] used simulated radar displays to compare color coded and black-and-white symbols. A second factor included was the number of irrelevant symbols (5 and 20). Effectiveness of the two experimental factors was assessed in a 2 x 2 design with repeated measurements. Color significantly affected the speed of target detection, but not the accuracy. Also, displaying 20 irrelevant symbols degraded performance no more than displaying 5. This latter finding is in conflict with the results of most of the previous density studies cited.

Wheatley,[72] studied the salience of three different coding dimensions (shape, color, numeral) in expressing hostility or threat. After

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[69] M. R. Jones. "Color Coding," *Human Factors*, 1962, 4(4), 355-365.

[70] S. L. Smith and D. W. Thomas. "Color versus Shape Coding in Information Displays," *Journal of Applied Psychology*, June 1964, 48(3), 137-146.

[71] M. Munns. *Some Effects of Display Symbol Variation Upon Operator Performance in Aircraft Interception*, NADS-MR-617, Naval Air Development Center, November 1967.

[72] E. Wheatley. "An Experiment on Coding Preferences for Display Symbols," *Ergonomics*, 1970, 20(5), 543-552.

instruction on how each dimension was used to express threat (seven levels), subjects chose which member of a pair of complex symbols (dimensions combined) expressed more threat. In actuality, the combinations were equated in threat value across the three code dimensions. However, subject choice was found to be determined more by shape or color than by numeral, with subjects usually choosing on the basis of only one dimension, rather than trying to evaluate all three.

The foregoing research seems to agree that the use of color as a coding dimension can enhance performance, particularly in search tasks. Combining color with other coding dimensions also can be advantageous up to a point. However, Conover and Kraft[73] point out some problems inherent in color coding: the limited number of hues absolutely discriminable under the best conditions, the substantial number of color-defective people (about 8% of all males), and the degradation of discrimination with highly chromatic light sources. In addition, some 12 to 20% of subjects with apparently normal color vision may exhibit anomalous color vision when viewing color patches smaller than 20 minutes of visual angle.

In essence, color coding can be very useful, but must be considered carefully for each given situation, and not used indiscriminantly just because it is available.

Alphanumeric Coding

Because the TOC system's function is primarily the display of graphic symbols (FM 21-30 or alternatives) and uses an acceptable preprogrammed alphanumeric, this section will be limited to a brief summary of the major findings in the research on electronic displays of alphanumeric codes.

Ketchel and Jenney[74] state:

> ...of all the coding techniques, alphanumeric has attracted the greatest attention because letters and numerals offer almost limitless possibilities for encoding information. The optimum characteristics of alphanumeric codes for various applications have been the subject of intense investigation over the years, and

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[73] Conover and Kraft, *op. cit.*

[74] J. Ketchel and L. Jenney. *Electronic and Optically Generated Aircraft Displays: A Study of Standardization Requirements*, JANAIR Report No. 680606, US Navy, Office of Naval Research, Washington, D.C., May 1968.

nearly half of the research reports ever published on symbology deal with some aspect of alphanumerics.

Rowland and Cornog,[75] in 1958, examined practically all commercially available fonts for use on air traffic control television display screens. Using group subjective evaluation, they found none of the fonts acceptable to the potential users. They composed a new (Courtney) font, and again used the subjective judgment of a user group. Their results indicated that the Courtney font was superior to all others for CRT displays.

Shurtleff and Owen[76] objected to the subjective evaluation method, used by Rowland and Cornog and devised a more objective method for evaluating legibility. They used a 14-inch video monitor connected to a 525 raster scan line TV camera to display both Courtney and Leroy fonts. Both speed and accuracy were used as measures of legibility. Symbol resolution was varied, each symbol was presented composed of either 8, 10, or 12 scan lines. Shurtleff and Owen found that with brief practice, Courtney symbols were identified less accurately and less rapidly than the Leroy symbols. However, increased practice eliminated these differences. Resolution was the only statistically significant variable.

Shurtleff, Marsetta, and Showman[77] then conducted a study comparing the Leroy font to a modified Leroy font (they altered the B, G, H, K, Q, S, Z, 1, 2, 5, and 7). The goal of their study was to determine the minimum symbol size which would result in 95% correct identification. Each symbol was presented at 6, 8, and 10 scan lines per symbol. Using a 21-inch monitor fed by a 945 scan line TV camera, they established minimum sizes for both fonts. Again, resolution was a significant source of variance, with the 8 and 10 scan line height giving the better results than 6 scan lines. Only the modified H and B were found to be more effective and were recommended for use with the remainder of the standard Leroy font.

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[75] G. E. Rowland and D. Y. Cornog. *Selected Alphanumeric Characters for Closed-Circuit Television Displays*, Technical Report #21, Civil Aeronautics Administration, Technical Development Center, Indianapolis, Indiana, July 1958.

[76] D. A. Shurtleff and D. Owen. *Studies in Display System Legibility: VI. A Comparison of the Legibility of Televised Leroy and Courtney Symbols*, ESD-TR-65-136, MITRE Corporation, Bedford, Massachusetts, May 1966.

[77] D. A. Shurtleff, M. Marsetta, and D. Showman. *Studies in Display Symbol Legibility: IX. The Effects of Resolution, Visual Size and Viewing Angle on the Legibility of Televised Leroy Alphanumeric Symbols*, ESD-TR-65-411, MITRE Corporation, Bedford, Massachusetts, May 1966.

Bell[78] compared two teletype fonts under approximately the same conditions (945 scan line camera, 14-inch monitor). Long Gothic was compared with Murray Style at 6, 8, 10, and 12 active scan lines per symbol height. No significant differences were found, due primarily to the use of a small number of subjects and extensive intra-subject variance.

Symbol Size and Proportion

In alphanumeric studies it is traditional to use the height of the symbol in inches as the main measure of size, then derive the other measures (symbol width, stroke width, spacing) as a percentage of symbol height.

Woodson and Conover[79] state: "In general, the larger the size of letters and numerals, the less we have to worry about backgrounds and illumination." But the problems with TOC systems are just the reverse; it may at times be desirable to maximize the amount of information displayed in a limited space. This must be accomplished, without increasing errors, by limiting the amount of information displayed at any one time or by making the presentation as small as possible.

Howell and Kraft[80] using Mackworth alphanumerics, studied the relationships among size, blur, and brightness on radar-type displays. They found that with no blur, .13-inch letters viewed at 28 inches were recognized with over 97% accuracy. However, they recommend .22-inch letters, particularly for limited brightness contrast under conditions of mild blurring.

In studying symbol width-to-height relationships, Soar[81] looked at height-to-width ratio, using AMEL numerals in a 4 x 4 design. He found no generally significant results for stroke-width. The 75% width-to-

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[78] G. Bell. *Studies in Display Symbol Legibility: XVI. The Legibility of Teletypewriter Symbols on Television,* ESD-TR-67-104, MITRE Corporation, Bedford, Massachusetts, April 1966.

[79] W. E. Woodson and D. W. Conover. *Human Engineering Guide for Equipment Designers (2nd Ed.),* Berkeley: University of California Press, 1966.

[80] W. C. Howell and D. L. Kraft. *Size, Blur and Contrast as Variables Affecting the Legibility of Alphanumeric Symbols on Radar-Type Displays,* WADC-TR-59-536, Laboratory of Aviation Psychology, Wright-Patterson AFB, Ohio, September 1959.

[81] R. S. Soar. "Height-Width Proportions and Stroke Width in Numerical Visibility," *Journal of Applied Psychology,* 1955, 39(1), 43-46.

height ratio was slightly superior to the 60%, and the 30% and 45% were both much poorer. However, the very short (.04 seconds) exposure times used led to high error rates. The very low illumination levels used were not very realistic and therefore it is difficult to generalize these findings to other conditions.

Crook, Hanson, and Weisz,[82,83] in two separate studies, examined the interrelationships of several variables with stroke width. In the first study they varied three letter heights, three levels of brightness contrast, two symbol spacings and three stroke widths. There were no significant differences for brightness contrasts above 90% nor for visual angles subtended which exceeded 22 minutes of arc. Varying stroke width had no effect. In the second study, Crook, et al. used three stroke widths, two values of symbol width-to-height, three symbol spacings (different spacings for each letter width-to-height) and two levels of illumination. The letters averaged 15.7 minutes of arc. Accuracy of identification approached 99% for all conditions except the low illumination level with the narrowest stroke width (8.8% to 9.8% of height). This combination yielded approximately 88% accuracy.

In apparent contradiction of findings by Crook, et al. Semple, et al.[84] suggest that the stroke width-to-height ratio of alphanumerics does indeed affect legibility. Under conditions of low brightness, low brightness contrast, or short exposure times, they recommend that stroke width range from 13.3% to 20% of the height. As noted by Crook, et al., with adequate brightness, brightness contrast, and exposure time, stroke width-to-height ratio ceases to be a significant factor in legibility.

Vartabedian[85] studied the effects of letter size and case on recognition time. He found that both matrix (7 x 9) and stroke letters were recognized faster in upper case than lower case. Kosmider[86]

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[82] M. N. Crook, J. A. Hanson, and A. Weisz. *Legibility of Type as Determined by the Combined Effect of Typographical Variables and Reflectance of Background*, WADC-TR-53-411, Wright Air Development Center, Wright-Patterson AFB, Ohio, March 1954.

[83] M. N. Crook, J. A. Hanson, and A. Weisz. *Legibility of Type as a Function of Stroke Width, Letter Width, and Letter Spacing Under Low Illumination*, WADC-TR-53-440, Wright Air Development Center, Wright-Patterson AFB, Ohio, October 1954.

[84] Semple, et al., *op. cit.*

[85] A. G. Vartabedian. "The Effects of Letter Size, Case and Generation Method on CRT Display Search Time," *Human Factors*, 1971, 13, 363-368.

[86] G. Kosmider. *Studies of Display Legibility. V: The Effects of Television Transmission on the Legibility of Common Five-Letter Words*, ESD-TR-65-135, MITRE Corporation, Bedford, Massachusetts, May 1966.

compared the recognition time of single letters and five-letter words in television type displays. He found that the words were recognized more rapidly than the single letters. The present authors assume that Kosmidor's results were due to the fact that word recognition is more frequently required in reading than single letter recognition.

In summary, it would appear that accurate and rapid recognition of alphanumerics in CRT displays poses no great problem, assuming that reasonable guidelines in generation are followed. These guidelines, which were abstracted from the studies reviewed, are as follows:

1. The symbol-to-background-contrast ratio should be maintained above 10:1, but not exceed 45:1.

2. The stroke width-to-height ratio should vary between 12:100 and 20:100, depending upon the particular symbol. However, for symbols subtending less than 16 minutes of arc, the ratio should be between 8:100 and 10:100.

3. The optimum symbol width-to-height ratio depends upon the particular symbol, but should be approximately 1:2.

4. For fastest possible recognition, symbol height should subtend 22 to 25 minutes of arc. Visual angles of less than 16 minutes of arc should be avoided.

5. Common fonts should be used. Variable stroke widths and/or serifs should be avoided. Recommended fonts are Mackworth, Lincoln/Mitre, Leroy, and MIL-M-18012.

6. The space between symbols should be no less than 25% of symbol height.

7. Viewing angles should be 20° or less for best results. However, angles up to 38° are acceptable if spacing between symbols is increased.

Considerable variation in alphanumerics appears to be permissible without any significant loss in either speed or accuracy of recognition. This is probably due to the "overlearning" of this symbol set occurring in our culture. Using alphanumerics, it is possible to "get away with" more overcrowding, angular distortion, and shorter exposure times than with any of the other coding methods. Nevertheless, as Shurtleff[87] stated in 1974: "The data are not complete enough, nor described in sufficient detail, for one to be able to specify unequivocally what the value of each relevant factor should be for a given display situation."

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[87] D. A. Shurtleff. "Legibility Research," *Proceedings of the Society for Information Display*, 1974, 15, 41-51.

Requirements for other than alphanumeric symbols are less clear. Semple, et al.[88] conclude that the current military symbols require from 33% to 100% more CRT scan lines than alphanumerics. They add that:

> ...resolution requirements for geometric symbols increase as a function of the detail of the symbol, increasing exponentially with complex figures (i.e., the identification of different aircraft by their shapes). Military type targets viewed against natural background (as opposed to a clear or unnatural background) require even more resolution to optimize identification. Unfortunately, little in the way of experimental work has been done in this area.

Requirements for topographic symbols are no more clear. This paper has not included a discussion of the problems associated with the projection of topographic details on computer-generated displays because there is very little literature available in this area. Only three recent reports relevant to the subject were found. Bramley[89] discussed the current and projected development of display technologies. Brooks, et al.[90] discussed the computer simulation of terrestrial views, and Murphy and Trelinskie[91] discussed the use of analog graphic processing techniques for possible computer projection of topographic information. These reports undoubtedly have important implications for the future. However, the notions expressed are largely untried, and therefore, their actual utility in an operational system is unknown. Berry and Horowitz[92] had naive subjects draw symbols (pictures, diagrams, abstractions, etc.) to represent 30 different topographical features. Even allowing for a lack of artistic ability, they found significant "agreement" between their subjects' representations and standard topographic

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[88] Semple, et al., *op. cit.*

[89] J. Bramley. *Display Technologies for Topographic Applications. Assessment of State-of-the-Art and Forecast,* US Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, June 1975.

[90] J. Brooks, L. Lichtenstein, and H. Steinberg. *Computer Simulation of Terrestrial Scenes,* US Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, July 1975.

[91] L. P. Murphy and E. G. Trelinskie, Jr. *Analog Graphic Processing for 3-D Terrain Displays, Profiles, and Elevation Layer Tints,* US Army Engineer Topographic Laboratories, Fort Belvoir, Virginia, October 1975.

[92] H. A. Berry and P. Horowitz. *Interpretation of Topographic Displays by Untrained Personnel,* Aeroneutronic Division, Ford Motor Company, March 1961.

symbols on only two of the 30 features. This result seems to indicate that the majority of the topographic symbols have little natural association value. Therefore, training personnel to accurately interpret the current set of topographic symbols is likely to be as difficult as training for interpretation of any other unfamiliar symbology. It is apparent that much is yet to be learned about the representation of topographic features in computer-generated displays.

Flash Rate Coding

This is an area which, for a variety of reasons, has received little experimental study.

Gerathewohl[93] investigated the conspicuity of three flash frequencies and duration rates. Frequencies were one, two, and four flashes per second, while durations were either 1/2, 1/4, or 1/8 second durations; luminance was held constant. Conspicuity of flashing was found to depend upon the frequency of flashes, not on the duration of a single flash. Response time was also faster when the flash rate was faster.

Baker and Grether[94] in their review found little data on flash coding. They were able to determine that under ideal conditions five flash rates could be absolutely discriminated. However, they felt that flash rate coding was generally unsatisfactory because of the high brightness required for high flash rates, and also because of the annoyance potential of the flicker effect.

Cohen and Dinnerstein[95] examined the relation between flash frequencies and the ability to correctly identify the frequencies. Using 10 subjects and nine flash rates ranging from .025/ sec. to 12/second, they found a maximum of five discriminable flash rates. When four rates of flash were used some errors of identification occurred, and they concluded that only three rates should be used under critical conditions; 240/min., 160/min., and 20/min. Morgan, et al.[96] concur and

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[93] S. J. Gerathewohl. "Conspicuity of Flashing Signals of Different Frequency and Duration," *Journal of Experimental Psychology*, 1954, 48(4), 247-251.

[94] Baker and Grether, *op. cit.*

[95] J. Cohen and A. J. Dinnerstein. *Flash Rate as a Visual Coding Dimension for Information*, WADC-TR-57-64, Wright Air Development Center, Wright-Patterson AFB, Ohio, May 1958.

[96] Morgan, et al., *op. cit.*

recommend that flash rates be limited to no more than four, and further counsel that they be limited to only one or two critical items on the display.

Ziegler, Reilly, and Chernikoff[97] conducted two experiments to determine the effects of adding flash coding. They also compared a display system which indicated error direction by flash coding with one where error direction was indicated by flash coding and error magnitude by symbol brightness.

In the first experiment subjects performed a compensatory tracking task in which they observed a flashing dot moving along the x-axis of a display. In one condition, flash was used to indicate direction of error. If the dot veered more than 1/8 inch above the reference axis, it flashed at 60 cycles per minute, if more than 1/8 inch below the reference line, it flashed at 120 cycles per minute. The flash rate supplied the subjects with "error direction" to allow correction of the line of traverse. Displacement plus flash was superior to displacement alone. In the second experiment, the conditions were the same, but the flash brightness was increased from 50 to 1200 foot-lamberts as an error displacement increased. As the error was decreased, the flash rate decreased, until at zero error the subject momentarily would see a steady light. After the two sessions, the "depth of flash" (brightness) condition had only half the error rate of the flash condition alone.

In summary, flash coding appears to be one of the least useful of the several coding dimensions available, and should be used only as a last resort. However, flash coding has some value as an attention-getting device for marking new or altered data on a visual display. Flashing codes should not be left "on" for very long, as they can be irritating to the observer.

There may be potential in the use of flash coding as a tracking device, particularly with the "depth-in-flashing" technique. However, such uses should be approached cautiously, and only after research and evaluation.

A concise summary of the research in an area such as this seems impossible. The number of combinations of symbology variables, situations, users, and responses seems overwhelming. However, the rationale behind this research effort was to provide assistance in the development of military symbology systems. Therefore, this section should at least provide some recommendations for future directions in research based on the literature review. Three recommendations seem appropriate. The first is that symbology studies should be conducted in situations as realistic (i.e., simulated combat) as possible. The second is that

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[97] P. N. Ziegler, R. E. Reilly, and R. Chernikoff. *The Use of Displacement, Flash, and Depth-of-Flash Coded Displays for Providing Control Information*, NRL Report 6412, Engineering Psychology Branch, US Navy Research Laboratory, Washington, D.C., July 1966.

complete symbol sets should be studied, as easily discriminable symbols may interact in unforeseen ways to affect both the speed and accuracy of interpretation. In composing any graphic (geometric) symbol alphabet for use at the Division level, it is estimated that 75 or more force symbols and approximately 100 topographic feature symbols may be required. Therefore, the third recommendation is that investigation be directed toward determining the advantages and/or disadvantages of utilizing selected or specialized subsets of symbols for different users. Many tradeoffs need to be studied. For example, should a single, all-purpose symbolic unit be employed, or should some users have a simplified symbol with alphanumeric readouts provided on request? The differential use of color and flash coding techniques for different users, especially to provide redundancy, is also in need of investigation.

Chapter 3

AN INVESTIGATION OF SYMBOL PREFERENCES

Background

It was noted in Chapter 1 that participants in MASSTER Test FM 116[1] felt that, while the symbology used was adequate, there could be some better coding system than the standard FM 21-31.[2] In addition, several sources cited in Chapter 1 indicated interest in the development of new and innovative approaches to graphic symbology for tactical use. In response to this preceived need, the authors of the present report devised a study intended to explore the preferences of relatively naive subjects in assigning symbols to represent military units commonly displayed by the CCIDES system. It seemed particularly important to determine the extent that non-military preferred current symbology when compared with alternative symbols.

Research Problem and Design

Twenty-four symbols commonly used in battlefield displays were selected from FM 21-30. The unit or function designations selected are listed in Table 3-1. Alternative symbols for these 24 designations were selected partially from the "Soviet Armed Forces Military Symbols,"[3] and supplemented with geometric and pictorial forms composed by the research staff.

For each of the 24 designations, four alternative forms were devised.

Subjects were asked to rank the four symbols in terms of how meaningfully they felt each symbol represented that particular designation. The 24 designations were presented in a list with four alternative symbols presented to the right of each designation. (In addition, subjects were given the opportunity to draw or describe other appropri-

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[1] H. B. Aldrich, et al. *IBCS: Automated Displays*, MASSTER Test Report FM 116, Headquarters, Modern Army Selected Systems, Test, Evaluation, and Review (MASSTER), Fort Hood, Texas, July 1974.

[2] US Department of the Army. Field Manual 21-30, "Military Symbols," 1970.

[3] US Department of Defense Intelligence Agency. "Soviet Armed Forces Military Symbols," AP-220-3-18-70-INT, October 1970. (FOR OFFICIAL USE ONLY)

Table 3-1. Unit or Function Designations Used On Symbol Ranking Form

1.	Infantry	13.	Observation Post
2.	Artillery	14.	Armored Cavalry
3.	Cavalry (Reconnaissance)	15.	Airmobile
4.	Signal	16.	Supply
5.	Antitank	17.	Transportation
6.	Engineer	18.	Surface-to-Air Missile
7.	Radar	19.	Surface-to-Surface Missile
8.	Air Defense	20.	Medical
9.	Chemical	21.	Maintenance
10.	Airborne	22.	Sensor
11.	Armored Infantry	23.	Ordnance
12.	Aviation	24.	Armor

ate symbols, although very few did so.) A copy of the directions and the symbol ranking form are included in Appendix A. Each symbol on this example form is marked as to its origin; American (U), Soviet (S), Geometric (G), or Pictorial (P). However, the subjects were not given this information. The items from the four lists were arranged so that representative symbols from each list appeared equally often in each position (from first to fourth) with no repetitions of order.

Subjects were 25 volunteer civilians at West Fort Hood, 12 males and 13 females. Nine of the males and two of the females had previous military service experience, but this factor was not found to influence the rankings.

Results and Conclusions

The data were analyzed in several different ways. First, the obtained rankings were tabulated separately for the males and females and tested to see if sex was a significant factor in determining differences in rankings of the four symbol sets. Spearman rank-order correlations[4] were computed on each list between the rankings of the males and females. All correlations were significant ($p < .01$) which indicated agreement between males and females on the rankings for all four of the lists. These correlations are shown in Table 3-2.

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[4] S. Siegel. *Non-Parametric Statistics for the Behavioral Sciences*, New York: McGraw-Hill, 1956.

Table 3-2. Rank Order Correlations Between Males and Females for the Four 24-Item Lists

A Symbol List	$r_s = .58, p < .01$
R Symbol List	$r_s = .58, p < .01$
F Symbol List	$r_s = .70, p < .01$
G Symbol List	$r_s = .83, p < .01$

Next, the combined (n = 25) ranks for each symbol within each designation were tested using Friedman's rank-sum test[5] to see if the four symbols differed significantly. The results are listed in Table 3-3. In 16 out of 24 cases a very significant ($p < .001$) difference in the mean rankings was obtained. Four cases differed to a lesser

Table 3-3. Results of the Friedman Test of Difference Among the Ratings Assigned the Four Symbols

Item	χ^2	$p <$	Item	χ^2	$p <$
1	30.744	.001	13	16.616	.001
2	21.464	.001	14	16.952	.001
3	28.168	.001	15	27.384	.001
4	6.552	.10	16	17.400	.001
5	28.696	.001	17	9.384	.05
6	15.464	.01	18	7.304	.10
7	10.136	.02	19	7.064	.10
8	31.384	.001	20	25.752	.001
9	21.176	.001	21	17.976	.001
10	22.200	.001	22	19.368	.001
11	15.416	.01	23	5.288	.20
12	18.296	.001	24	20.376	.001

degree ($p < .05$), and differences observed for the remaining four cases were not significant. Therefore, it can be concluded that these 25 subjects generally agreed on their rankings on the majority of the symbol sets. However, while these results show that for a particular set

[5] *Ibid.*

of four symbols the subjects significantly agree on their rankings, they do not reveal the source of the significance. That is, the subjects agree highly that one symbol is most (or least) meaningful, but they may not agree on their rankings of the other three symbols. Alternatively, significance may indicate that the subjects agree on their rankings of all four of the symbols, or any combination between these extremes. Therefore, in order to determine which symbol or symbols were ranked significantly different from one another, the rankings were further analyzed pairwise using a posterior Nemenyi test.[6] This test allows all possible pairwise comparisons to be made without increasing the probability of Type II error. For example, the ranking of the first symbol on the rating form for the designation, INFANTRY, can be tested for significance against the ranking of each of the other three symbols. In this example, the test showed that the second symbol, B (from the list), was more meaningful (lower rank sum) than any of the other three symbols. The first symbol, A (from the U list), was not ranked significantly different from C (G list) but was significantly more meaningful (lower rank sum) than D (S list). C, however, was not ranked significantly different than D. The results of this test for all 24 items are listed in Table B-1, Appendix B. In most cases one symbol in each set was ranked most meangingful or least meaningful, while the remaining symbols did not significantly differ. Table 3-4 summarizes the results of the pairwise comparison. Overall, there were 17 of the 24 designations where one symbol was either definitely the most preferred or the least preferred.

The final comparison of these data was to separate the rankings by source list across the 25 subjects. Again, using the Friedman test, it was established that the four symbol lists were ranked significantly different ($p < .001$) from one another across the 24 designations (items). Again, using the Nemenyi test, it was found that in general (across the 24 items), the pictorial list symbols were ranked significantly lower (more meaningful), while the Soviet list symbols were ranked significantly higher (least meaningful). The current US military symbols (U list) and the geometric symbols list were not ranked significantly different from each other, but were both between the pictorial list rankings and the Soviet list rankings.

The conclusions to be drawn from this rather limited investigation are weakened by requiring the subjects to rank four symbols for how meaningfully the symbols represent a particular military designation. This task is only very remotely associated to the tasks faced by an operator utilizing a graphic symbol display on a CRT in a TOC. In the TOC, the operator would be presented with symbols which represent many

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[6] M. Hollander and D. A. Wolfe. *Nonparametric Statistical Methods*, New York: John Wiley & Sons, 1973.

Table 3-4. Designation for Which Significant Performers Were Found

Designation	Most (Least) Meaningful Symbol Type(s)
Infantry	Pictorial
Artillery	Pictorial
Cavalry	Pictorial
Signal	(Soviet)
Antitank	Pictorial
Engineer	Pictorial
Radar	(Soviet)
Air Defense	(US)
Chemical	Pictorial
Airborne	Pictorial
Armored Infantry	No significant difference
Aviation	Geometric or Pictorial
Observation Post	Pictorial
Armored Cavalry	No significant difference
Airmobile	Pictorial
Supply	(US)
Transportation	Soviet
Surface-to-Air Missile	No significant difference
Surface-to-Surface Missile	No significant difference
Medical	No significant difference
Maintenance	(Soviet)
Sensor	Geometric
Ordnance	(US)
Armor	Pictorial

units with the same symbol displayed simultaneously with those for many different types of units. However, the current investigation did show that several of the current military symbols used by the Army are not highly regarded as meaningful by inexperienced subjects. Unfortunately, symbols which are the generally most meaningful are also the most complex and would be difficult to program for a CRT display and would also create more "clutter" than most of the existing symbologies.

Chapter 4

OVERVIEW AND CONCLUSIONS

After reviewing a large amount of research on techniques appropriate for automated graphic display, it is apparent that the Army really has two different but associated problems. Personnel operating a tactical graphic system in combat must analyze a massive amount of data, summarize it, and decide exactly what material is important and should be brought to the attention of the commander. It seems essential therefore that all levels, from battalion to division to corps to Army, must systematically organize and prioritize the types and amounts of information for each area of responsibility. A decision must also be made as to what constitutes optimal data for each area commander. This data must allow the commander to reach the best possible tactical decision at any particular moment in an ongoing combat situation.

In order to achieve the goal of optimizing information presentation and utilization, the Army must concern itself with the dual tasks of first approaching each display user or user function with a very precise and detailed study of the minimum amount of data (and other information sources) that a particular user actually requires. This minimum data must allow the user sufficient information to pass on selected items to a higher level of command. Secondly, care must also be taken to determine the form or type (graphic, alphanumeric, color, etc.) of display which will optimize the user's ability to fulfill his function. Then a task analysis at the top level of commands could be completed for each and every function required for decision making. This analysis could be performed in lieu of one which would attempt to determine all possible information requirements at each level. As a consequence of this analysis, perhaps much of the symbology display requirements could be reduced to a more feasible level.

Currently proposed symbologies should be tested for their ability to augment or even replace the current symbologies at each of the using levels and/or functions. This study could be expected to support a case for the use of several different symbol sets, each most appropriate for a particular function.

From the information garnered in the literature review section, it would appear that an alternative symbol alphabet or an alphanumeric symbology could be easily trained. The alphanumeric set could have an important advantage in that the meanings of the symbols (letters) are well learned in our culture. This high degree of learning would allow combinations of symbols to be economically used. Numerals could be used appropriately to indicate either number of a type, such as APC9 for nine armored personnel carriers, or size of a unit such as 8TK for a tank division.

The overall conclusion reached in this discussion of symbology for automated graphic displays is that the primary specification for the optimal number of displays and the most useful set of specific symbols remains to be established. This specification would require a consensus at all levels and functions as to at what level, who requires, at a minimum, what information. Only after these questions have been answered can satisfactory progress be made in determining the optimal symbols system or systems for maximizing combat operations efficiency and effectiveness. Or, an alternative design approach is to provide what anyone wants, but to allow individual console operators to suppress and otherwise temporarily edit the symbol set to be used.

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APPENDIX A

THE SYMBOL PREFERENCE FORM

Directions

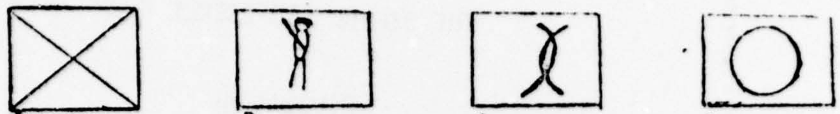
On each of the following pages there are four (4) symbols used or proposed by several countries as military symbols to identify 24 different activities or functions. For each activity, please look at the four symbols and rank them from 1 - appears to identify most meaningfully that activity; to 4 - appears to identify least meaningfully that activity. Do this for each of the 24 activities.

THANK YOU FOR YOUR COOPERATION.

SEX _____

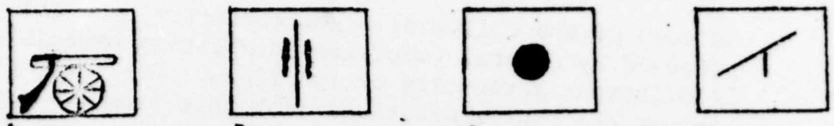
MILITARY SERVICE? _____

1. INFANTRY



A___ B___ C___ D___

2. ARTILLERY



A___ B___ C___ D___

3. CAVALRY (RECONNAISSANCE)

A___ B___ C___ D___

4. SIGNAL

A___ B___ C___ D___

5. ANTITANK

A___ B___ C___ D___

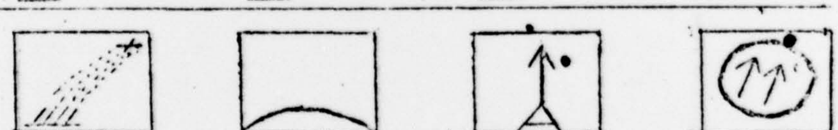
6. ENGINEER

A___ B___ C___ D___

7. RADAR

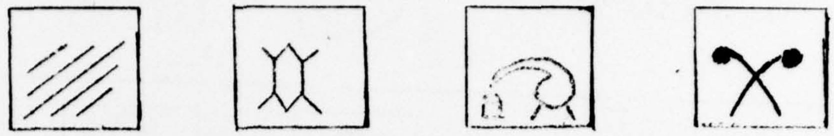
A___ B___ C___ D___

8. AIR DEFENSE



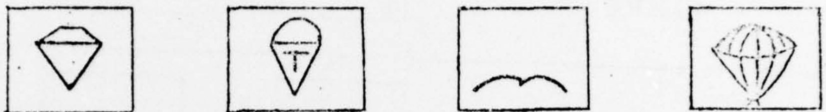
A___ B___ C___ D___

9. CHEMICAL



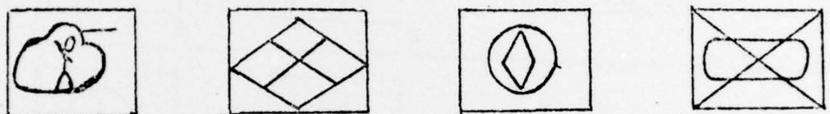
A___ B___ C___ D___

10. AIRBORNE



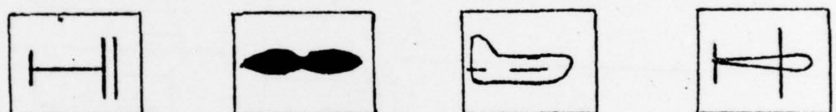
A___ B___ C___ D___

11. ARMORED INFANTRY



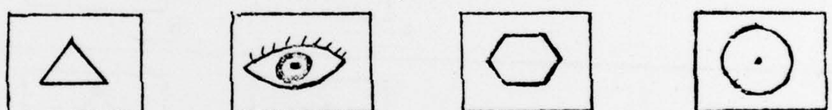
A___ B___ C___ D___

12. AVIATION



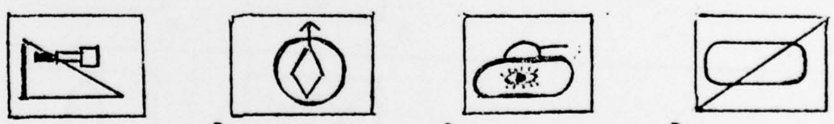
A___ B___ C___ D___

13. OBSERVATION POST



A___ B___ C___ D___

14. ARMORED CAVALRY (RECONNAISSANCE)



A___ B___ C___ D___

15. AIRMOBILE

A___ B___ C___ D___

16. SUPPLY

A___ B___ C___ D___

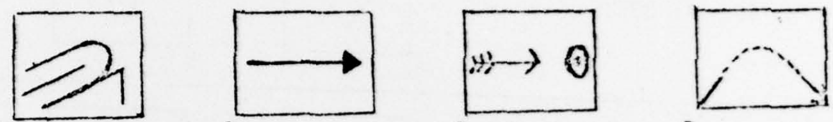
17. TRANSPORTATION

A___ B___ C___ D___

18. SURFACE-TO-AIR MISSILE

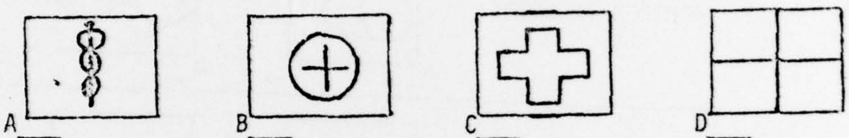
A___ B___ C___ D___

19. SURFACE-TO-SURFACE MISSILE



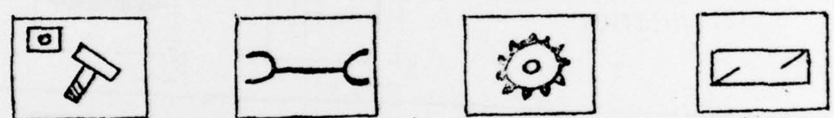
A___ B___ C___ D___

20. MEDICAL



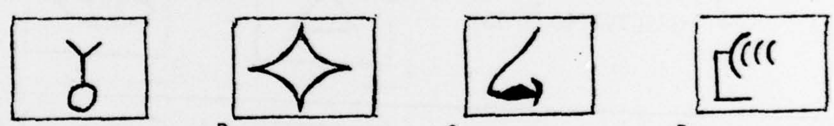
A___ B___ C___ D___

21. MAINTENANCE



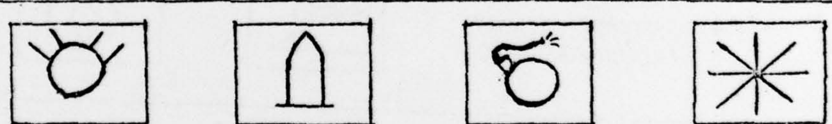
A___ B___ C___ D___

22. SENSOR



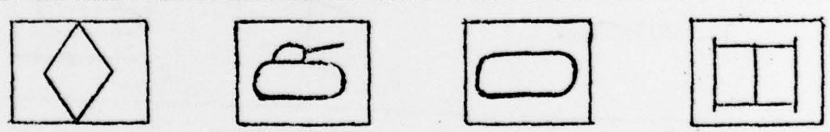
A___ B___ C___ D___

23. ORDNANCE



A___ B___ C___ D___

24. ARMOR



A___ B___ C___ D___

APPENDIX B

Table B-1. Results of Nemenyi Pairwise Comparisons Test (Letters underlined by a common line represent the symbols which were not ranked significantly different.)

1. B A C D	13. B D A C
2. A B C D	14. C A D B
3. D A C B	15. B C A D
4. B D C A	16. B D A C
5. A D B C	17. B A D C
6. C B A D	18. A DC B
7. C A B D	19. D C A B
8. A C D B	20. C A B D
9. C D B A	21. A C B D
10. D B C A	22. D A C B
11. A D C B	23. C B D A
12. D C B A	24. B C A D